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Correlation of Impression Removal Force with Elastomeric Impression Material Rigidity and Hardness

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Abstract

Purpose: Difficult impression removal has been linked to high rigidity and hardness of elastomeric impression materials. In response to this concern, manufacturers have reformulated their materials to reduce rigidity and hardness to decrease removal difficulty; however, the relationship between impression removal and rigidity or hardness has not been evaluated. The purpose of this study was to determine if there is a positive correlation between impression removal difficulty and rigidity or hardness of current elastomeric impression materials.
Materials and Methods: Light- and medium-body polyether (PE), vinylpolysiloxane (VPS), and hybrid vinyl polyether siloxane (VPES) impression materials were tested ($n = 5$ for each material/consistency/test method). Rigidity (elastic modulus) was measured via tensile testing of dumbbell-shaped specimens (Die C, ASTM D412). Shore A hardness was measured using disc specimens according to ASTM D2240–05 test specifications. Impressions were also made of a custom stainless steel model using a custom metal tray that could be attached to a universal tester to measure associated removal force. Within each impression material consistency, one-factor ANOVA and Tukey's post hoc analyses ($\alpha = 0.05$) were used to compare rigidity, hardness, and removal force of the three types of impression materials. A Pearson's correlation ($\alpha = 0.05$) was used to evaluate the association between impression removal force and rigidity or hardness.
Results: With medium-body materials, VPS exhibited significantly higher ($p \leq 0.05$) rigidity and hardness than VPES or PE, while PE impressions required significantly higher ($p \leq 0.05$) removal force than VPS or VPES impressions. With light-body materials, VPS again demonstrated significantly higher ($p \leq 0.05$) hardness than VPES or PE, while the rigidity of the light-body materials did not significantly differ between materials ($p > 0.05$); however, just as with the medium-body materials, light-body PE impressions required significantly higher ($p \leq 0.05$) removal force than VPS or VPES. Moreover, there was no positive correlation ($p > 0.05$) between impression removal force and rigidity or hardness with either medium- or light-body materials.
Conclusions: The evidence suggests that high impression material rigidity and hardness are not predictors of impression removal difficulty.

Current impression materials used for prosthodontic applications include vinylpolysiloxane (VPS), polyether (PE), and vinyl polyether silicone (VPES). VPS is inherently hydrophobic due to the material's aliphatic hydrocarbon groups surrounding the siloxane bond.[1,2] To overcome this limitation, manufacturers incorporate surfactants (nonylphenoxypolyethanol homologues)[3,4] and market the materials as hydrophilic VPS. In contrast, PE impression material is inherently hydrophilic, because its functional groups, carbonyl (C = O) and ether (C-O-C), attract and interact with water molecules; thus, the material does not require the inclusion of surfactants.[2,4,5] VPES is considered a hybrid of VPS and PE with organopolysiloxane combined with PE in a 1:2 ratio and a nonionic surfactant and/or a PE-modified silicone oil added.[6]

Over the years, high rigidity and hardness of elastomeric impression materials have been linked to more difficult impression removal of PE impressions.[7-11] To address this issue, some PE materials have been reformulated to reduce rigidity

Table 1 Impression materials used

Product	Manufacturer	Type	Consistency	Lot No.
Impregum Soft	3M ESPE	PE	Medium	349600
	St. Paul, MN		Light	381019
Aquasil Ultra Xtra	Dentsply/Caulk	VPS	Medium	070622
	Milford, DE		Light	090427
EXA'lence	GC America	VPES	Medium	0810241
	Alsip, IL		Light	0905291

and hardness in order to decrease removal difficulty.[4,12] At the same time, a recent VPS impression material is being promoted as "like polyether, but polyeasier."[13] The product brochure includes information about hydrophilicity (wetting) similar to PE, but with easier impression removal than PE. Besides updated PE and VPS, a hybrid VPES impression material has also potentially addressed issues related to impression removal difficulty. One VPES manufacturer claims that the material combines the best features of PE and VPS, that is, the intrinsic hydrophilicity of PE but with low rigidity to allow easy impression removal.[14]

While impression material rigidity as reflected by elastic modulus, compressive strain, or hardness has been evaluated previously, those studies included older formulations of PE with higher rigidity.[9,10,15] However, a 2004 study evaluated reformulated PE and reported that it was less rigid than VPS.[16] Nevertheless, while working on another in vitro study, we observed that impressions made with the less rigid PE still seemed more difficult to remove than VPS impressions. Interestingly, despite the conventional belief that impression material rigidity is associated with impression removal difficulty, this relationship has never been evaluated.

The objectives of this investigation were to assess rigidity and hardness and their relationship to impression removal force with three types of impression materials (PE, VPS, VPES). The research hypothesis was that there would be a positive correlation between impression removal force and impression material rigidity or hardness.

Materials and methods

Light and medium PE, VPS, and VPES impression materials were used in this study (Table 1). All materials were mixed and dispensed according to manufacturer recommendations. As per ISO 4823 specification,[17] materials were allowed to polymerize in a $35 \pm 1^{\circ}$C distilled water bath to simulate oral conditions. Based on a power analysis of preliminary data, it was determined that five specimens of each material/consistency per test method would meet the constraints of $\alpha = 0.05$ and power $= 0.80$.

Rigidity (elastic modulus)

Rigidity (elastic modulus) was measured via a tensile test using dumbbell-shaped specimens made from a mold as specified in ASTM D412, die C.[18] Specimens were 3 mm thick with the dimensions of the reduced portion of the dumbbell at 33×6.4 mm. During polymerization, the filled mold was held between two glass plates with metal clamps on either end and placed into the water bath. Immediately following polymerization, specimens were tested under tensile stress at a rate of 500 mm/min until failure (as per ASTM D412) using a universal tester (Model 1125/5500R, Instron Corp, Norwood, MA). The rigidity (modulus of elasticity) was calculated based on the slope of the linear portion of the generated stress/strain curve.

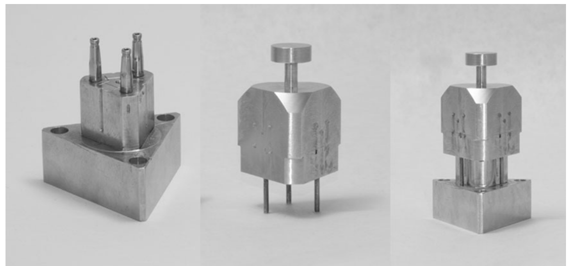

Figure 1 Custom metal model and tray with stops on the model base.

Shore hardness

Specimens and measurements followed ASTM D2240–05 specification for Shore A hardness measurements.[19] Five disks were made of each material using a 6.5-mm thick polyvinyl carbonate ring mold having an inner diameter of 40.3 mm. During polymerization, specimens were placed between two glass plates held firmly together by two metal clamps and placed in the water bath. Following polymerization, three hardness measurements (Model 9130–035 Shore-A Durometer, Instron Corp) were made on only one side of each disk at a location 12 mm from any edge and at least 6 mm from any previous indent. The three measurements were used to generate a mean measure per specimen.

Removal force

Impressions were made of a custom stainless steel model using a custom spaced tray with stops on the model base (Fig 1). The model, which was developed for a previous study,[20] included three stainless steel implant analogs/replicas with metal impression copings in a triangular arrangement 10 mm apart. Prior to making each impression, appropriate tray adhesive was applied to a clean internal tray surface and allowed to dry for 15 minutes. Impression materials were injected around the implant copings prior to seating the filled tray on the model. The model/tray assembly was placed in the 35°C water bath with a 100 g weight placed on top of the tray to ensure a similar force and stability during polymerization. After polymerization was complete, excess material beyond the tray border was trimmed to ensure a consistent volume of material for each impression. After attaching the model/tray assembly to the mechanical tester, the impression was removed vertically using a tester speed of 25 mm/min. Maximum load to remove the impression was recorded.

Data analysis

Within each impression material consistency, a one-factor ANOVA and Tukey's post hoc test ($\alpha = 0.05$) were used to compare the rigidity, hardness, and removal force of the three

Table 2 Rigidity, hardness, and impression removal force means (SD) of three types of impression materials and two consistencies

Impression material (type), consistency	Rigidity (GPa)	Hardness (Shore A)	Removal force (N)
Impregum Soft (PE), medium	2.29(0.06)[b]	53.3(2.3)[c]	*287.0(21.6)[a]
Aquasil Ultra Xtra (VPS), medium	*3.43(0.11)[a]	*68.1(0.8)[a]	243.0(22.6)[b]
EXA'lence (VPES), medium	2.17(0.05)[c]	57.7(0.5)[b]	165.3(20.3)[c]
[1]Means (SD) across medium body	2.62(0.60)	59.7(6.5)	231.8(49.1)
Impregum Soft (PE), light	1.34(0.08)[A]	41.2(1.3)[C]	**215.7(35.5)[A]
Aquasil Ultra Xtra (VPS), light	1.35(0.02)[A]	**50.9(0.8)[A]	122.2(27.7)[B]
EXA'lence (VPES), light	1.33(0.05)[A]	48.1(0.7)[B]	136.6(35.3)[B]
[2]Means (SD) across light body	1.34(0.05)	46.7(4.3)	158.1(52.4)

*Medium-body VPS exhibited significantly higher rigidity and hardness, while medium-body PE required significantly higher removal force. Lowercase letters indicate subsets within medium-body material measurements.

**Within light-body materials, VPS exhibited significantly higher hardness, while PE required significantly higher removal force; however, there was no significant difference in rigidity between the materials. Uppercase letters indicate subsets within light-body material measurements.

[1,2]Within either medium- or light-body materials, there was no positive correlation between impression removal force and rigidity or hardness.

types of impression materials. Pearson's correlation ($\alpha = 0.05$) was also used to evaluate the association between removal force and rigidity or hardness of the three types of impression materials within each consistency.

Results

The means and SD of the various test methods are presented in Table 2. Based on the statistical analyses, medium-body VPS exhibited significantly higher ($p \leq 0.05$) rigidity and hardness than PE or VPES, while medium-body PE demonstrated significantly higher ($p \leq 0.05$) impression removal force. With the light-body materials, again VPS demonstrated significantly higher ($p \leq 0.05$) hardness, but there was not a significant difference ($p > 0.05$) in rigidity between the three types of material; however, light-body PE demonstrated significantly higher ($p \leq 0.05$) removal force than the other light body materials. Despite lower rigidity and hardness, both light and medium PE impressions required higher removal force. Moreover, there was not a significant positive correlation ($p > 0.05$) between impression removal force and rigidity or hardness with either light- or medium-body materials.

Discussion

The results of this study did not support the research hypothesis that impression removal force is positively correlated with impression material rigidity or hardness. Although PE impressions required higher removal force than VPS or VPES, PE did not exhibit the highest rigidity or hardness. In fact, medium-body VPS was significantly more rigid and harder than either the PE or VPES. With the light-body materials, VPS again exhibited the highest hardness, but the rigidity values were similar among PE, VPS, and VPES. In terms of comparing impression removal force between consistencies, the required force was lower for counterpart light-body materials, but PE removal force was significantly higher within both groups.

While the evaluation of statistically significant differences and correlations in impression removal force, rigidity, and hardness was critical to this study, it is also important to consider some other statistical analysis parameters. For example, effect size can be used as a standardized index independent of sample size to quantify the effect of impression material type (PE, VPS, or VPES) on the dependent variables.[21,22] With medium-body materials, effect sizes (based on partial eta squared values) were 0.77, 0.96, and 0.99 for removal force, rigidity, and hardness, respectively. These effect size values indicate that 77% to 99% of the differences in the respective dependent variables were due to impression material type. With light-body materials, there were significant differences in removal force and hardness associated with 0.66 and 0.96 effect size values, respectively. In contrast, with light-body materials there was no significant difference in rigidity as a function of material type, and the associated effect size was only 0.04. Another important consideration is observed power; in this study, power levels ranged from 0.97 to 1.0 across significant dependent variables. For light-body material rigidity, which was not significantly different as a function of material type, the power level was 0.08. A power level of 0.08 is very low; however, as already mentioned, the associated effect size was also low, 0.04. Because effect size is independent of sample size, increasing the sample to potentially detect a "significant" difference associated with 4% of the rigidity variance of light-body materials would not be appropriate. Nonetheless, despite these additional considerations, the overall study focus outcome indicated there was no positive correlation between impression removal force and rigidity or hardness.

Although there have been previous studies of impression material rigidity and hardness, most of those studies are older and did not include materials evaluated in this study.[9,10,15] In those older studies, PE was more rigid and harder than the other evaluated elastomeric materials. To our knowledge, only one study has evaluated the rigidity of a more recently reformulated PE, and that study reported that the reformulated "soft" PE was less rigid than VPS and previous PE materials.[16] Those results are similar to this study; however, to date, no previous investigation has included an evaluation of impression removal force, so there are no results to which we can compare that integral component of our study.

As with any in vitro investigation, there are limitations. For example, the stainless steel model used in this study does not include undercuts similar to those in the dental arch or simulate the properties of oral tissues, which would exhibit higher resiliency than the metal model. Moreover, the impression removal protocol is not the same as clinical impression removal; however, while the generated force values associated with removing the impression from the model would not translate into clinical values, the study design allows relative comparisons between materials to provide insight into which material requires more impression removal force. In the same way, although the study protocol evaluations of rigidity and hardness do not simulate clinical applications, following standard/specification protocols for rigidity and hardness measurements facilitates study replication and comparisons.

The results of our study do not support the conventional belief that impression removal force is positively correlated with impression material rigidity and hardness. A possible explanation for why reformulated PE exhibits a higher impression removal force despite lower rigidity and hardness could be related to PE's inherent hydrophilicity and potential associated friction. It has been reported that hydrophilic polymeric materials exhibit a higher friction coefficient than hydrophobic materials.[23-25] With hydrophilic elastomers, the surface energy and associated interfacial interactions are strong, leading to a high friction coefficient.[25] Numerous investigations have confirmed that unset and set PE exhibits significantly greater hydrophilicity and surface energy than VPS materials despite the addition of hydrophilic surfactants to VPS.[26–29] In view of that, perhaps the higher removal force associated with PE material could be explained by its high hydrophilicity and associated surface energy leading to potentially higher associated friction between the impression material and the surface over which it must slide during removal; however, another factor is the hydrophilicity of the impressed surface and its role in the coefficient of friction.[25] In this investigation, the interaction was between the impression materials and the stainless steel model. Dentin and enamel demonstrate a lower contact angle than stainless steel, approximately 50, 57, and 70, respectively.[30-32] In other words, dentin and enamel are more hydrophilic than stainless steel. Thus, it might be expected that the interaction between the more hydrophilic impression material (PE) and the mineralized tooth surfaces could produce an even higher coefficient of friction.

While both medium- and light-body PE materials are hydrophilic, the light-body material required lower removal force. This suggests that removal force may be related to more than just hydrophilicity. For example, materials with high flow and better detail reproduction might result in a more intimate relationship with the impressed surface, which could potentially affect impression removal; however, to confirm these possible explanations, further research is required.

In conclusion, our results indicated that while there were significant differences in impression removal force, rigidity, and hardness, impression removal force was not positively correlated with rigidity or hardness. Based on this evidence, high impression material rigidity and hardness should not be used as predictors of impression removal difficulty. This information should be considered to update the concepts taught regarding impression material applications in prosthodontics.

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